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User's Guide to Selection of Blasting Abrasives -- Final Report

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
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in cooperation with
Peterson Builders, Inc.

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User's Guide to Selection of Blasting Abrasives

Final Report

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1. Executive Summary

The purpose of this guide for abrasive selection is: through proper abrasive selection shipyards can improve productivity, reduce waste, and decrease the costs associated with abrasive blast cleaning.

Abrasive blasting is generally acknowledged to be the most effective and efficient means of surface preparation. Blasting accounts for about two-thirds of the cost of the surface preparation and coating operation, which is itself, a major cost component of shipyards. The wide variations in types of abrasive, blasting processes and operator proficiency, result in huge fluctuations in the efficiency and cost of the abrasive blasting operation. Therefore, significant reduction in cost and improvement in production can be attained by proper selection and use of abrasives, meeting the objective of this project; to develop a shipyards guide to select abrasive and blasting parameters that will optimize this activity.

The guide allows the user to perform the following analyses:

- **<u>Estimating productivity and consumption rates</u>**

  Blasting productivity (sq. ft. per hr.) and abrasive consumption rate (lbs of abrasive per sq. ft., or lbs of abrasive per hr.) are computed for various conditions. These quantities are derived from an 11 step procedure. The user is asked to define the existing surface (i.e., Type and condition of coating or metal) and the end condition (i.e., degree of cleaning and profile) sought. The model computes productivity and consumption rates for 13 abrasives under one of four blasting pressures from between 90 to 125 psi and one of three different nozzle sizes, ranging between sizes 6 and 8. Adjustment to these basic rates can be made for factors such as the accessibility of the area to be cleaned, the elevation and the need for special controls (e.g., of dust). These computations are based on data derived from industry and literature surveys (see discussion below).

- **<u>Estimating costs for specific shipyard blasting activities</u>**

  Costs are computed from the following components: shipyard labor (blasting and set up), abrasive materials, and waste disposal. The model computes costs per sq. ft. based on user input forlabor factors, type and size of project, type of abrasive, nature of waste (hazardous or non-hazardous), along with other parameters described above, the model computes costs per sq. ft.

- **<u>Benchmarking shipyard blasting operations</u>**

  The model also allows the user to compare current shipyard blasting productivity, abrasive consumption rates and costs with this guides industry norms. The user is guided on how to determine actual production and consumption rates for the shipyard for direct comparison with the data from the industry survey.

The guide can be operated in an electronic version or hard copy version. The latter uses a handbook format with data provided in a well-indexed look-up tables.

The databases on productivity and consumption rates were derived from an extensive search of data from published literature, and from experiences of abrasive users and suppliers. These are available in electronic format.

The literature review is described in the second of our interim deliverables, previously submitted to NSRP Program Management. It describes basic characteristics of abrasives, the blasting process, illustrates the principal factors affecting production/consumption and other performance parameters.

Shipyard experience with the use of abrasives is summarized in Section 6.C.

The project also entailed a review and analysis of regulations affecting the use of abrasives and of available standards for abrasives from the government, commercial and international sources. These analyses are referenced in Section 6. A summary of available standards is given in Section 6.D.

2. Introduction

This project provides a "User’s Guide to Selection of Blasting Abrasives." The guide can help reduce the overall cost of surface preparation, a critical cost component in shipbuilding. Shown below is the original abstract published by NSRP for this project. Following the abstract is a description of the scope of the project and its key deliverables.

A. Abstract of Project

The following is the abstract for the project.

Title: “User’s Guide to Selection of Blasting Abrasives”

Objective: Provide a comprehensive guide to abrasive selection based on qualification, cleaning capability, physical properties, costs, surface quality, productivity, safety and environmental impact.

Background: Surface preparation by abrasive blasting involves a wide variety of cleaning requirements for new construction and ship repair. These range from cleaning of preconstruction primer and light rust to removal of thick coatings, heavy rust and marine growth. The market offers a multitude of choices of one-time use and recyclable abrasives.

In order to execute a credible analysis, several factors must all be taken into account: personal hygiene, environmental impact, waste disposal, material cost, productivity, cleaning effectiveness, coating performance, climatic effects, cleanliness standards (for both new and recyclable) and equipment costs. This study will provide the data, standards and tests upon which decisions can be based.

Technical

Task 1: Identify all types of abrasives available to user for both single use and recyclable (i.e., metallic, mineral, synthetic, by-product, agriculture, etc.) Define characteristics of each. Collect latest standards or specifications for each type.
Task 2: Collect performance data. Identify cost drivers.
Task 3: Outline safety, health, environmental, cleanliness and disposal requirements. Define all associated regulations.
Task 4: Develop test models to stimulate typical shipyard applications.
Task 5: Provide comprehensive cost models to support the abrasive selection process.
Task 6: Produce a standard guidance document for abrasive selection.
Task 7: Write Report

Benefits: Shipyards will have a comprehensive guidance document to abrasive performance, cleanliness and cost.

B. Scope and Key Deliverables

The scope of the project is to provide a comprehensive guide to the selection of abrasives. This guide addresses key factors in abrasive selection such as:

- Cleaning capability;
- Physical properties;
- Costs;
- Surface quality;
- Productivity;
- Safety, and
- Environmental impact.

The seven deliverables were:

Deliverable 1: A report summarizing the different types of abrasives, industry specifications and consensus standards defining each abrasive type.

Deliverable 2: A report describing the performance properties of different abrasive types. The report contains productivity and consumption data gathered from both a technical literature review, and surveys of abrasive manufacturers or users.

Deliverable 3: A report describing the regulatory impact on abrasive selection and use from health, safety and environmental regulations. The report contains information about respiratory effects of different types of abrasive and also addresses waste disposal issues.

Deliverable 4: This report describes a process for modeling the abrasive productivity and consumption in typical shipyard applications. The data used to create the report is taken from the earlier industry surveys and technical literature sources identified in deliverable 2.

Deliverable 5: A second modeling exercise assessed costs associated with abrasive use. This model builds on the data contained in deliverable 4 and creates a cost model for surface preparation. Using the model, estimates of the costs for typical surface preparation tasks are made.

Deliverable 6: The guide to abrasive selection provides a user with a way to make abrasive selections based on their knowledge of the surface preparation task. The productivity and consumption information shown in the guide come from databases created for deliverable 4. Guidance on cost estimating is based on the model database created for deliverable 5.

Deliverable 7: This report, describing how the project was conducted, and its key deliverables.

C. How Project Can Benefit Shipyards

This project benefits shipyards by helping them control a significant component of the cost of building a vessel. Surface preparation and coating account for at least five percent of the total cost of a vessel, according to the work of Peterson Builders in their report for NSRP.[1] Surface preparation costs alone can account for over two-thirds of the cost of surface preparation and coating.[2] The efficiency of surface preparation is critically dependent on the method used for cleaning. The most widely used method of surface preparation is abrasive blasting. This is because it is more cost effective than alternative methods, such as High Pressure Water Jetting or power tool cleaning. Optimizing the abrasive blasting process by improving the efficiency of the abrasive blasting process and reducing abrasive consumption can yield significant cost advantages.

1. NSRP Report Number 0302, “The Economics of Shipyard Painting Phase II, Bid Stage Estimating.”
2. Good Painting Practice, Volume 1 of the Steel Structures Painting Manual, Chapter 8.0, “Comparative Painting Costs,” 3rd Edition, SSPC 1993.

There are many abrasives available to a user. Each abrasive has unique physical and performance characteristics. There are also a variety of surface preparation tasks faced by a shipyard, for new construction and for maintenance activities. Properly matching the abrasive to the task at hand can result in the following:

- Reduced rework of cleaned and coated surfaces;
- Improved production rates;
- Reduced waste disposal costs, and
- Improved cost efficiency.

The guide and database deliverables produced in this project give a user the tools needed to select the best abrasive. Specifically, these tools guide the user to:

- Determine production and consumption rates for a specific choice of abrasive;
- Determine the expected consumption and labor costs of the use of this abrasive, and
- Measure the users process against the expectations for performance suggested by the guide.

The net results to a shipyard are a reduced cost of operations and an enhanced competitiveness.

3. Description of Project Tasks and Deliverables

The primary goal of the project was the delivery of a user’s guide to selection of abrasive materials. This user’s guide to abrasive selection was the sixth deliverable. The five earlier interim deliverables, in the form of technical reports and electronic databases, provided the materials for creation of the user’s guide.

A. Description of Information Searches and Associated Deliverables

There were three deliverables associated with our information search. The first of these was a report which summarized available technical information on abrasive material types, specifications describing abrasives and industry standards for abrasive performance.

The second of these deliverables focussed on abrasive performance and consumption characteristics. It was the result of two information search efforts. One of these efforts was a literature search to elicit information on abrasive consumption, productivity and physical characteristics. The second effort was to acquire information on abrasive consumption and productivity from the marine community, the general painting industry and from abrasive manufacturers.

The third of our information reports summarized the impact of health, safety and environmental regulations on abrasive selection and use.

A.1 Literature Surveys for Industry Standards and Specifications

Part of the first deliverable was a survey to identify industry standards and specifications. This first deliverable also included information on classification of abrasive materials. The information search was conducted through a review of the technical literature and SSPC’s technical libraries of consensus specifications and standards. Major sections of the first deliverable dealing with industry specifications and standards are described below.

A.1.1 Standards for Blast Cleaning Abrasives

This section describes commercial, military and international standards and specifications for abrasive materials.

Description of Standards

The most complete, and most recently issued, set of standards for blast cleaning abrasives is that from the International Organization for Standardization (ISO). There are four main ISO standards pertaining to blasting abrasives. Each of these is composed of several parts, each part dealing with a specific abrasive or test method. The pertinent parts of the various ISO standards are condensed into a set of tables in deliverable 1. The ISO requirements for both metallic abrasives and non-metallic abrasives are also tabulated. The ISO abrasive size designations are correlated with the Society of Automotive Engineers (SAE) J444 size designations. Sieve analyses are given for each abrasive size. The SSPC specifications for metallic and non-metallic abrasives are discussed. Efficiencies and cleaning rates from proprietary sources are referenced from SSPC’s Steel Structures Painting Manual for selected non-metallic abrasives.

The military specifications MIL-A-21380 and MIL-A-22262(SH) for metallic and mineral abrasives are discussed.

Additional information is given which correlates the metric size designations found in the ISO specifications with the corresponding U.S. units from the SSPC or SAE specifications.

All the specifications and standards contain chemical and composition requirements. Many include performance measures (such as shape retention, hardness or friability). The way these requirements are described differs from one standards setting body to another, this makes it difficult to directly compare one document with another. Performance or composition requirements for all specifications are tabulated to make overcome this difficulty.

Discussion of Abrasive Material Classes

The specifications also contain generic descriptions of abrasive materials. These descriptions are used to form the basis of a classification system shown later on page 21. The hardness, relative toughness, and specific gravity of many non-metallic abrasives are discussed. The common mineral make-up and other distinguishing characteristics of each abrasive are tabulated.

Description of Key Abrasive Characteristics

The relevance and impact of key abrasive characteristics are discussed. Specific topics addressed included:

- Hardness
- Toughness
- Specific Gravity
- Abrasive Sizing, and
- Classification of Mineral Slag Abrasives

A.2 Literature Surveys for Abrasive Productivity and Consumption Data

The literature search for information on abrasive productivity and consumption is reported in our second deliverable on abrasive productivity and performance. The following sources of information were examined:

- SSPC Technical Libraries - These include the complete series of editions of the Journal of Protective Coatings and Linings, Materials Performance, and other technical publications in the field of surface preparation and coating. In addition our technical libraries include a number of conference proceedings from SSPC, NACE and other technical societies such as ASTM. Furthermore our holdings include nearly all of the prominent books and technical reports regarding abrasives, abrasive use, and surface preparation.
- University Library Services - Many of the articles relevant to the subject of abrasive use and abrasive productivity were already available to SSPC through its technical libraries. When articles, reports or books were absent from our technical libraries they were obtained through the library services of the Carnegie Mellon University or the University of Pittsburgh.
- Electronic Information Searches - We performed broad based information retrievals of abstracts for technical articles concerning abrasives, abrasive use, abrasive performance, surface preparation productivity, surface preparation costs and health, safety and environmental impacts of abrasive use in surface preparation.The information on abrasive productivity and consumption rates for different cleaning tasks from these articles was extracted and placed in a spreadsheet database for future use.

A comprehensive literature review based on the retrieved articles has been prepared. This review summarizes the relevant information about abrasive productivity and consumption. It also discusses the importance of abrasive characteristics to abrasive performance. This review contains a comprehensive bibliography.

Over 200 articles relevant to abrasive use and performance are abstracted for review; of these:

- A total of fifty-three articles from JPCL or SSPC conference proceedings are described in an annotated bibliography;
- An additional eighteen technical publications from SSPC or other industry sources are used as reference materials.
- Thirty-seven of these articles or sources are used as primary reference material.

Contents of Report on Abrasive Performance, Productivity and Consumption

The second deliverable consists of 114 pages. It is divided into nine sections. The subject matter covered by each sections is as follows:

- Section I provides introductory information and the report structure.
- Section II describes the major categories and types of abrasives used in shipyards and the most commonly used specifications.
- Section III describes the most significant physical, chemical and performance properties.
- Section IV provide an understanding of the interaction between different abrasive properties and the ability to prepare a surface or productively use an abrasive.
- Section V provides documented or reported productivity measurements for the use of typical abrasives under simulated or real operating conditions.
- Section VI presents the results from a survey of US Shipyards on estimates for production rates in typical surface preparation tasks.
- Section VII presents data on productivity and performance based on a survey of manufacturers (sub-section A) and users of abrasive (sub-section B).
- Section IX provides information on the literature sources discussing surface preparation productivity or production rates.

A.3 Industry Surveys for Abrasive Use and Productivity & Consumption Data

To supplement the information on abrasive performance and consumption retrieved from the technical literature is a set of surveys. These surveys target three distinct audiences. The first audience is the marine and shipbuilding industry. Second, is the general painting industry. Third, are the abrasive manufacturers. In each instance we obtain estimates of abrasive productivity and consumption when conducting defined surface preparation tasks. The definition of these tasks include the following parameters:

- The nature of the original surface coating;
- The degree of cleaning to be achieved;
- The desired profile of the specification;
- The pressure at the abrasive blasting nozzle;
- The size (and type) of abrasive blasting nozzle;
- The identity of the abrasive used, and
- The size of the abrasive used.

This information is entered into a second set of databases. The intention is to compare the median productivity and consumption rate estimates with those found in the technical literature. As part of our survey of manufacturers we also include copies of any documents defining the physical properties of commercially available abrasives.

The results of these surveys become a part of our second deliverable (Section VI) describing abrasive performance, productivity, consumption and characteristics.

A.4 Literature Survey for Pertinent Regulations

Environmental, health, and safety regulations play an important role in shaping many engineering processes, such as surface preparation prior to painting. There are several types of impact seen from regulations on surface preparation.

Regulations can impact on the choice and manner of abrasive usage. For instance, if the resultant waste material is hazardous and difficult to dispose of, a reusable abrasive may be chosen, in order to limit waste generation. Similarly safety and health regulations may limit the use of specific abrasives based on the level of silica (a known hazardous material). If emissions are of concern, then a lower dusting abrasive may be chosen, or the entire process altered to restrict emissions (through the use of containment, for instance).

Review of Regulations Impacting Abrasive Use or Selection

This report contains the following sections:

1. Impact of Regulations on Abrasive Choice and Use

The ways in which regulations can affect abrasive choice and use are described. Particular emphasis is placed on recognizing and controlling hazards from free silica, heavy metals, nuisance dusts and other regulated materials found in abrasives, or generated by abrasive blasting. Following this general discussion the most important health, safety and environmental regulations are summarized, focussing on portions of each regulation relevant to surface preparation or abrasive use. The individual standards discussed are described below.

2. Health and Safety Regulations, Standards and Hazards

The OSHA Marine Industry Standards (29 CFR 1915) is discussed with particular focus on the following areas:

- Exposure to heavy metals (cadmium, arsenic, lead);
- Exposure to respirable silica;
- Medical monitoring program requirements;
- Respiratory protection measures, and
- Confined space working requirements.

3. Navy Specification on Abrasive

The restrictions on radioactive materials, heavy metals, arsenic, and chromium found in MIL-A 22262 B(SH) are described.

4. Specific Health and Safety Hazard

The likelihood of exposure to the identified hazards of silica, heavy metals and to nuisance dusts is explored. This is done by reference to the technical literature and related SSPC studies. Guidance is given on selection of abrasives and surface preparation processes which limit worker exposure.

5. Assessment of Environmental Regulations

A review of the impact of each environmental regulation was presented.

The environmental regulations covered included:

- The Resource Conservation and Recovery Act (RCRA);
- The Clean Air Act (CAA) and amendments;
- The Clean Water Act;
- The Comprehensive Environmental Response Compensation and Liability Act (CERCLA), and
- The Federal Insecticide, Fungicide and Rodenticide Act.

6. Relevant Controls on Abrasive Emissions and Disposal from General Industry Practice

General industry practice for control of abrasive emissions and disposal of abrasive wastes is described in this section. Comparison is also given to marine industry practice when known.

7. Survey of State Environmental Regulations

Some states impose more stringent rules than the federal environmental regulations. A survey was made of the states with the largest numbers of known shipyards to determine what added regulations these shipyards work under.

Overall, the most significant impact of the regulations surveyed are in these four areas of abrasive use:

- Paint removal of materials containing hazardous metals (particularly cadmium or lead);
- Waste disposal of materials generated during abrasive blasting;
- Reduction in free silica containing abrasives, and;
- Restrictions in emissions of nuisance airborne dusts during abrasive blasting.

B. Abrasive Performance and Cost Modeling

A key requirement for the user's guide was to facilitate the process of estimating production rates and surface preparation costs. The approach taken to meet this requirement was the development of abrasive performance and cost models. Raw data on abrasive consumption and productivity provided the cornerstone of our models. This information was organized into databases. These databases were then used as the basis for production of an electronic version of our performance and cost models. These electronic products, along with raw data output constitute our fourth and fifth deliverables.

Originally the expectation was that two separate deliverables would be made. The first deliverable was to be a report, database and data used in performance modeling. A subsequent deliverable would cover the cost modeling database in a similar fashion. During the development of the performance modeling database it became clear that both database modeling applications were closely linked to one another. As a result the two databases were combined.

B.1 Abrasive Consumption and Productivity Databases

Our fourth and fifth deliverables include databases which contain abrasive consumption and surface preparation production rate data. The data sources used for these databases were derived from searches of the technical literature along with surveys of U.S. shipyard paint departments and their abrasive suppliers.

A report was prepared which describes the databases and their content. This report provides information on the process used to acquire, categorize, validate and display information on abrasive performance and abrasive blasting costs. Included in the report are the following sections and subsections:

- Goals of Modeling Tasks
- Database Development Activities
    - Acquisition of Data
    - Modification of Acquired Data
    - Structuring of Databases
- Additions to Database Modules
- Goal Attainment in Modeling Task
    - Suggested Models with Examples
- Future Work
- Appendices

- Tables of Working Data from Databases

The goal of these modeling tasks was to assess the impact of different variables on the production and consumption rates for use of abrasives.

The data for the models was acquired under Tasks 1 through 3 of this project.

B.2 Validation of Data

The original source data used in the productivity and consumption databases came from three information searches. Sources used were:

- SSPC literature (publications and reports);
- Technical literature sources, and
- Results of industry surveys.

Discrepancies were found between the reported production and consumption rates in each information source. It was vital to assess the reliability and validity of the different data sources. First, we compared the variables accounted for in each set of data. Then we merged information from the different data sets. Next, any data gaps were filled by mathematical interpolation, this provided a complete production rate and consumption rate databases. These databases were then consolidated. Finally, the consolidated data set was subjected to a controlled review by both abrasive manufacturers and users. Feedback from this review was used to modify numbers in the consolidated data sets. This process eliminated gaps and discrepancies in the production and consumption rate data.

B.2.1 Variables in the SSPC Literature Data Set

The SSPC data largely came from the two volumes of the Steel Structures Painting Manual, Chapters 2.0 through 2.4 of Volume 1, "Good Painting Practice," and Chapter 2 of Volume 2, "Systems and Specifications." The data on abrasive consumption and production rates from these two volumes accounts for the following parameters:

- The type of surface being cleaned is new, millscale bearing, steel.
- The type of mineral abrasive used is one with a density close to 100 lbs/ft^3. Metallic abrasives have a bulk density close to 300 lbs/ft^3.
- The type of structure cleaned was flat steel plate.
- The production and consumption rate information was obtained under controlled conditions.

The published data in this set only covers a limited range of conditions. It is comparable with a sub-set of data from the other two sources. When comparable conditions from the other two data sets were compared with one another, reasonably close agreement (± 25%) was seen in production and consumption rates.

B.2.2 Variables in Technical Literature Data Set

The technical literature data set provided very wide ranges of production and consumption rates. The data covered a much larger combination of variables. Variables accounted for in this data set include:

- Type of surface - the original surface conditions for which data was available fell into four general categories:

* Light Rust, Light Millscale or Loose Paint. This is a deteriorated surface which requires little effort to clean.

* Tight Rust or Tight Millscale. This is new sheet steel plate.
* Thin Paint or Rusted Thin Paint. This is previously coated steel plate where the coating thickness is no more than 5 mils.
* Thick Paint, Heavy Millscale or Heavily Pitted Rust. This can be steel plate where the coating thickness is greater than 10 mils.
- Coating hardness - the type of coating hardness fell into three general categories:
* Hard coating - typically a chemically cured coating such as an epoxy or urethane, or zinc-filled coating.
* Soft coating - typically a more readily deformed surface such as an alkyd, latex, or chlorinated rubber coating.
* No coating (new millscale bearing steel).
- Level of cleaning achieved fell into four categories:
* SSPC-SP 5 "White Metal Blast Cleaning."
* SSPC-SP 10 "Near White Metal Blast Cleaning."
* SSPC-SP 6 "Commercial Blast Cleaning."
* SSPC-SP 7 "Brush-Off Blast Cleaning."
- Profile created could be divided into three categories:
* Low Profile Range - Between 1.5 and 2.5 mils.
* Medium Profile Range - Between 2.5 and 4.0 mils
* High Profile Range - Over 4.0 mils.
- Types of abrasive used fell into the two broad categories of mineral and metallic abrasive. Within the category of mineral abrasives, data was found on ten mineral abrasives. For metallic abrasives, data was found for iron and steel grit, shot, and mixtures of shot and grit.

Most data in the technical literature was obtained under controlled conditions. The pressure at the abrasive blast nozzle, nozzle size, abrasive feed rate and other factors were identified. For some data from the technical literature the conditions of operation were poorly defined. Such poorly defined data from the technical literature was given less weight in our final production and consumption rate databases.

B.2.3 Data from Industry Surveys

Surveys were made of U.S. shipyard painting departments, abrasive manufacturers, and industrial contractors. A common survey instrument was used to obtain production rate and consumption rate data from all parties. The industry surveys attempted to gather data on typical applications, for which performance modeling of abrasives was desired. In the case of shipyards the applications included:

- Preparation of bilges during maintenance;
- Removal of pre-construction primer at weld seams on a new vessel;
- Removal of anti-skid deck coatings;
- Removal of millscale from new plate steel;
- Coating removal from selected non-ferrous surfaces, and
- Other tasks defined by the survey recipient.

The survey recipients were asked to show whether or not the production and consumption rate information was an estimate, or was it obtained under controlled conditions. When producing our production and consumption rate databases, greater weight was given to sources reporting data acquisition under controlled conditions.

When the data did not fit with a pre-defined cleaning task the survey participant was asked to identify the task being performed. This proved useful in categorizing and comparing data from industrial contractors and U.S. shipyards. Typically, industrial contractors reported information for cleaning of complex structural shapes. Shipyards were better able to respond with data fitting one of the pre-defined tasks. Shipyards also provided added task definitions. These new task definitions were incorporated into our final database. Industrial contractor production rates were often lower than those reported by U.S. shipyards. Only when reporting on cleaning of plate and structural steel did the data from industrial and shipyard sources converge.

Data from abrasive manufacturers was used to provide information on abrasive density, size and profile achieved during cleaning.

B.2.4 Merging of Information from Different Data Sets

Having identified the variables in each data set the production and consumption rate information was merged. To achieve a uniform merging of data each data point was tagged with codes representing relevant variables and factors. Data points were tagged to identify the following information:

- Type of surface;
- Coating hardness;
- Level of cleaning achieved;
- Profile created;
- Type and size of abrasive used;
- Operating conditions, (pressure at nozzle and nozzle size);
- Data acquisition parameters (controlled or estimated);
- Source of information (technical literature or survey information);
- Blast cleaning task description, and
- Complexity of surface (flat steel plate or structural steel shapes).

Data from the manufacturer survey was used to add physical characteristics such as size, shape, and density. Task descriptions were divided into twelve categories; see Section B.3, on page 15.

Data was sorted into subsets in which information obtained under identical conditions was directly comparable. The range of values of production or consumption rate within each sub-set was determined. Then the degree of agreement between survey data and technical literature data was determined for sets obtained under controlled conditions. By and large, when survey data obtained under controlled conditions is compared with technical literature data, a reasonably high degree of agreement was seen between the two data sources.

B.2.5 Filling in Gaps in the Data Sets

A performance and consumption rate database model demanded information for cleaning of steel surfaces under a wide variety of conditions. Our review of data sources showed gaps in the recorded information. To help fill in gaps we had to identify relationships between the known data, based on identified variables and then perform an exercise of data interpolation and extrapolation. This exercise used qualified data, such as that from the technical literature, as a benchmark. For instance, data was available which allowed us to assess the influence which the following factors have on abrasive productivity:

- Pressure at the nozzle;
- Nozzle size;

- Abrasive particle median size;
- Coating thickness, and
- Surface/Coating type.

Relationships between production or consumption rates and each of these factors were graphed. These graphs gave mathematical relationships from which production or consumption under other conditions could be calculated.

Production rate data sets were extended by extrapolation to cover conditions of higher nozzle pressure and larger nozzle size. These relationships were non-linear. For instance, production rates may increase 1.5% for each one pound increase in pressure at the nozzle above 100 psi. Thus, an increase in pressure at the nozzle of ten percent (100 psi to 110 psi) can increase production rates by 16%. Gaps in data within a data set were filled by interpolation. Interpolated numbers for production or consumption had to agree with the original relationship identified for the factor being graphed.

Benchmark data on abrasive consumption from the technical literature was dependent on the operating conditions. Consumption is linearly dependent on abrasive bulk density. Filling in gaps in the consumption data for abrasives became a simple computation. Ratios of bulk density were computed between our benchmark abrasives and abrasives with data gaps to develop abrasive consumption information. These ratios were used to extend consumption information beyond the information found from all data sources.

B.2.6 Consolidating Production and Consumption Rate Data

Following the exercise of filling in gaps in the data sets, a revised database was constructed. This database included information for production and consumption rates for thirteen mineral and three reusable abrasives. All original data, and any extrapolated or interpolated data, were included. This resulted in some redundancies in the full data set. To eliminate redundancies we tested the data as follows:

- If the data was acquired under controlled conditions it was retained;
- If the data was estimated, but and within ± 25% of our benchmark or literature data, it was retained;
- If the data showed greater than ± 25% disagreement with our benchmark data it was tagged as questionable.

Questionable data was partitioned from our database.

Data was sorted into sub-groups once again. Where more than one data point existed for a given set of operating and task conditions this data was averaged. A new database was created which contained production and consumption rate information with only one data point for any abrasive under a specific set of operating and task conditions.

B.2.7 External Review of Consolidated Data Sets

The consolidated data set was extensive. Over 12,000 combinations of abrasive type and operating conditions were represented. An external review of the full database content was not feasible. Instead, a representative sub-set of the consolidated data-set was prepared. This sub-set covered the most common operating conditions used in a shipyard setting (nozzle sizes from #6 through #8, ($^3/_8$-inch to $^1/_2$-inch diameter,) and pressures at the nozzle from 80 psi to 125 psi). Production and consumption information was given for each combination of pressure at the nozzle and nozzle size. This information was given for a minimum of five abrasive materials. The abrasive materials were randomized among recipients of this data validation survey. (Abrasive manufacturers always received a copy of data relevant to their product line.) Recipients were asked to comment on whether the data was within ± 25% of the expected value. If the data was within this range then no further modification was given to the data. If the data was outside of acceptable range then the recipient was asked to provide data, obtained under controlled conditions, to change the affected data points.

Values in the database were changed as needed based on the results of this validation survey. This revised version of the database constituted our final version and was used throughout the rest of the project.

B.3 Description of Abrasive Costs Database and Model

The earlier survey on production and consumption rates provided basic data needed to estimate surface preparation costs for twelve shipyard surface preparation tasks. The tasks with production rate and consumption information were:

- Cleaning of New Steel Plate or Steel Shapes - Task A
- Removal of Pre-Construction Primer - Task B
- Refurbishment or Recoating of Anti-Fouling Coatings - Task C
- Total Removal of Anti-Fouling and Anti-Corrosive Hull Coatings - Task D
- Removal or Refurbishment of Existing Deck Coatings - Task E
- Removal or Refurbishment of Coatings from Interior Spaces - Task F
- Removal or Refurbishment of Coatings from Superstructure - Task G
- Removal or Refurbishment of Existing Bilge or Ballast Coatings - Task H
- Cleaning of Machinery Housings - Task I
- Cleaning of Non-ferrous Surfaces (Aluminum, Zinc) - Task J
- Weld Seam Preparation - Task K

Baseline production rate information did not reflect level of difficulty caused by location, or through the use of an alternative surface preparation method.

It was recognized that the degree of difficulty of a surface preparation task plays a role in determining overall efficiency and cost. From the data reported by U.S. shipyards on production and consumption rates for individual tasks, we were able to develop factors that estimated maximum production rates for challenging tasks. These factors account for difficulties caused by the type of structure being prepared, its position and the height of the area in or on the vessel.

The actual method of removal also determines overall efficiency. Multiplication factors were developed to represent the efficiency of an alternative surface preparation process. Such alternative approaches to surface preparation find use when meeting regulatory restrictions.

Examples of the process rate modification factors developed are shown in the Table 1 on page 16.

Examples of the location rate modification factors are shown in Table 2 on page 16

Table 1: Production Rate Modifiers when Meeting Environmental Regulatory Constraints

Engineering Control	Production Rate Modifier	Abrasive Selection Impact	Other Comments
Open Air Abrasive Blasting (standard)	1.0	Typically mineral abrasives chosen	Default method
Wet Abrasive Blasting	0.75	Cannot use metallic abrasives	Clean up needed, flash rusting likely
Low Volume Water Slurry Blasting	0.85	Cannot use metallic abrasives	Lower clean-up than wet abrasive blasting, flash rusting limited
Vacuum Blasting	0.1 - 0.2	Recyclable abrasives preferred	Equipment heavy, production rate falls off with time
Ultra High Pressure Water Jetting (>25,000 psi)	0.25	Abrasive injection rare	No profile production
Vacuum Assisted Power Tool Cleaning (SSPC-SP 11)	0.15	Media described in specification.	Limited range of profile, productivity falls off with time.
Recycling with Containment	0.6	Recyclable abrasives preferred.	Modifier reflects moving and placing containment

Table 2: Production Rate Modifiers Based on Work Location

Location	Production Modifier
Hull Section - Easily Reached	1
Complex Steel Shape - Less than 25ft Elevation	0.75
Hull Section - 26-75 Feet High	0.75
Complex Steel 26-75 Feet High	0.75
Hull Section 76-150 Feet High	0.50
Complex Steel 76-150 Feet High	0.50
Interior Tank Space - Little Structural Steel	0.50
Interior Tank Space - Complex Structural Shapes	0.25

Together, the two sets of location and process modifiers are used to revise production rates for a defined task and process combination. This revised production rate also affects overall abrasive consumption.

B.4 Final Version of Abrasive Performance and Cost Models

Following revision of the raw data as described in paragraph B.2 on page 11 a final version of the performance and cost models was developed. This included both the production and consumption rate databases, tied to a database module which computed costs based on factors described in paragraph B.3 on page 15. A simple point and click user interface was provided for user input and presentation of modeling results. This interface along with the other database modules comprise a custom application.To model costs using the cost module of the database application requires user input of cost data for labor rates, equipment operating costs, waste disposal costs, and all task information.

This final version of the abrasive performance and cost model database was delivered as an attachment to the written "User’s Guide to Abrasive Selection," described below.

C. Description of the User’s Guide to Abrasive Selection

The guide provides information on the selection of abrasives based on:

- Task Descriptions;
- Cleaning Capability;
- Physical Properties;
- Costs;
- Surface Quality Requirements;
- Productivity in Use
- Safety, and;
- Environmental Impact.

Abrasive blasting may be used for a wide variety of surface preparation tasks during new construction and ship repair. These range from cleaning of preconstruction primer and light rust to removal of thick coatings, heavy rust and marine growth. The market offers a multitude of abrasives from which a user can choose. Some abrasives are used only once, others are recycled. Some abrasives are general purpose while others have more specialized applications.

To choose a suitable abrasive, a user must analyze surface preparation task requirements and match those to the production characteristics of available abrasives. Production characteristics include abrasive productivity, cleaning effectiveness, and cleanliness standards, for both new and recyclable materials. Climactic effects may control the way an abrasive is handled or used. Cost is always an important issue. Costs include the abrasive material, surface preparation equipment and waste disposal. Finally, there is the influence of health and safety, and environmental regulations on the choice or use of an abrasive. Such regulations may lead to different choices of abrasive or surface preparation method. These choices affect the cost for a surface preparation task. This guide simplifies choosing an abrasive. Information about a chosen abrasive reflects available data, industry standards and abrasive test methods. Users can figure out costs for a surface preparation task using the cost model included in the guide.

C.1 Versions of The Guide

The written guide is a text version of the database application containing the productivity and cost databases. All the data on productivity and abrasive consumption contained in this guide come from the database. The guide can be used separately from the database application, or it can be used in conjunction with the database.

C.2 Contents of the Guide

1. Introduction

This section of the guide provides a description of the major sections in the guide.

2. Using Guide for Estimating Abrasive Production and Consumption Rates

This section of the guide describes how to estimate production rates (sq ft/hr) and consumption rates (lbs/sq ft) for various abrasives. This is done by defining different surface conditions, operating parameters and other factors in an 11 step process: The steps taken are shown in Figure 1 on page 19, along with specific choices at each step.

Step 1 Describe The Surface to be Cleaned. -- Note choice as code number
Step 2 Determine Coating Hardness.. -- Note choice as code number
Step 3 Choose Cleaning Grade. -- Note choice as code number
Step 4 Choose Profile Range. -- Note choice as code number
Step 5 Choose Table with Code Carried Over. (Code number generated by choices made in Steps 1 through 4.)
Step 6 Determine Productivity at Expected Operating Conditions.
Step 7 Compare With Other Disposable Abrasives?
Step 8 Consider Using Recycled Abrasives?
Step 9 If Needed, Identify Alternative Method for Control of Dust Emissions
Step 10 Describe Impact of Work Location and Elevation.
Step 11 Estimate Total Waste Production.

Based on this information a user can:

- Estimate consumption and production rates, for one or more abrasives based on defined conditions using literature data. Data tables are provided for all conditions defined in the guide.
- Compare 2 or more abrasives for above parameters.
- Determine one or more properties of one or more abrasives (e.g., consumption rate, production rate) for specific application.

Figure: 1 Flow Chart for Abrasive Selection

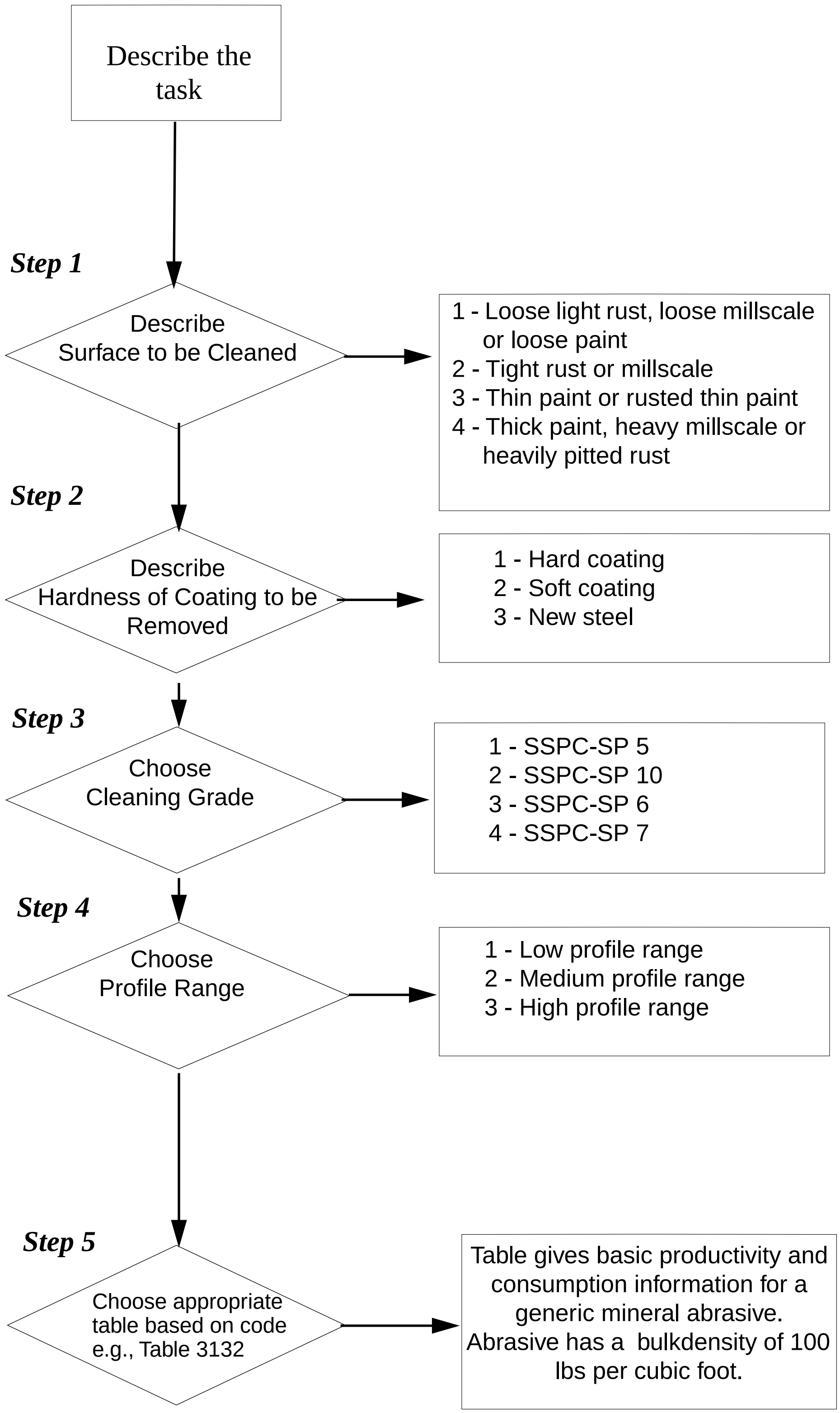
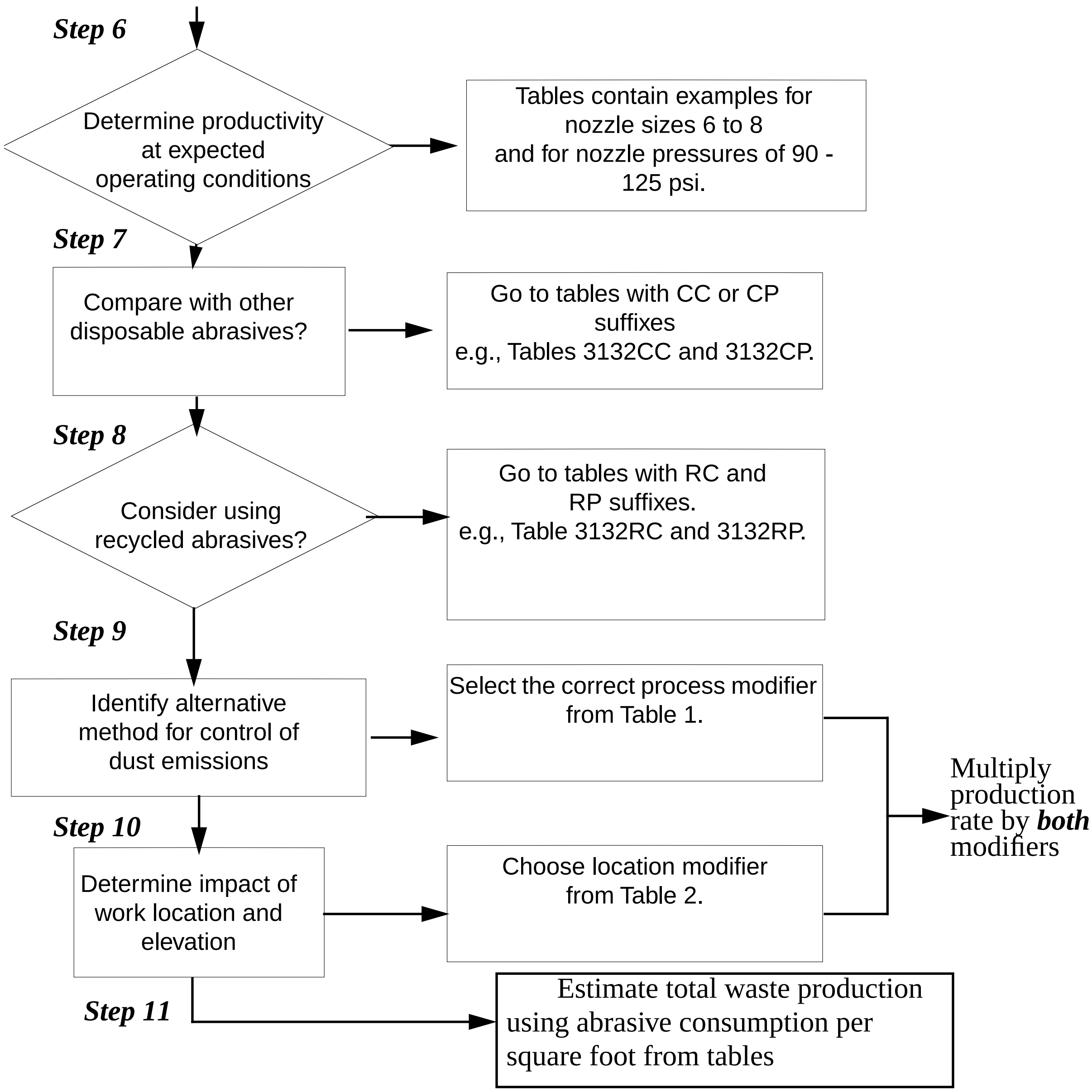


Figure: 1 Flow Chart for Abrasive Selection (Continued)



3. Using Guide to Estimate Costs for a Specific Task

This section contains a brief description of how to take the production and consumption rate information from Section 2 and use this to develop costing for individual surface preparation tasks.

4. Comparing Productivity and Consumption Data with Shipyard Data

One use of the information in the guide and its data tables is to benchmark a surface preparation process. This section provides information on how a shipyard should approach production and consumption rate data gathering. Guidance is also given on measures to take to optimize the surface preparation process.

5. Overview of Abrasives Used at Shipyards

This section describes why abrasives are used in a shipyard setting, the types of tasks requiring abrasives and how abrasives are bought and used.

The types of abrasives covered in the guide include the following types:

- Type I Metallic Abrasive - Sub-Divided into Grit and Shot
- Type II Mineral Abrasives
- Type III Recyclable Mineral Abrasives
- Type IV Organic Media
- Type V Plastic pellets
- Type VI Sponge encapsulated abrasive
- Type VII Sodium bicarbonate slurry
- Type VIII Carbon dioxide pellets

Typical tasks requiring surface preparation or surface treatment covered by the guide include:

- Cleaning of New Steel Plate or Steel Shapes - Task A
- Removal of Pre-Construction Primer - Task B
- Refurbishment or Recoating of Anti-Fouling Coatings - Task C
- Total Removal of Anti-Fouling and Anti-Corrosive Hull Coatings - Task D
- Removal or Refurbishment of Existing Deck Coatings - Task E
- Removal or Refurbishment of Coatings from Interior Spaces - Task F
- Removal or Refurbishment of Coatings from Superstructure - Task G
- Removal or Refurbishment of Existing Bilge or Ballast Coatings - Task H
- Cleaning of Machinery Housings - Task I
- Cleaning of Non-ferrous Surfaces (Aluminum, Zinc) - Task J
- Weld Seam Preparation - Task K
- Degreasing or Oil Removal - Task L

Other influences on abrasive selection include need to reduce waste material volume, to limit the emission of airborne dusts, or to minimize exposure to silica or trace metals from the abrasive. The guide provides tabulated combinations of tasks and suggested abrasive (or alternative surface preparation processes if this is appropriate). Suggested alternate processes include:

- AP I - Portable rotary wheel blasting.
- AP II - High pressure water jetting.
- AP III - Power tool cleaning, without vacuum recovery of dust.
- AP IV - Power tool cleaning, with vacuum recovery of dust.
- AP V - Vacuum abrasive blasting.
- AP VI - Wet abrasive blasting.

These choices suggested by the guide document are shown in Table 3 on page 22.

Table 3: Combination of Tasks and Abrasive or Process Choices

Task Description	Commonly Used Abrasive	Alternative Choice	Choice Based on Waste Reduction	Choice Based on Dust Control
Cleaning of New Steel Plate or Steel Shapes - Task A	Type I	Type II	Type I or Type III	AP VI
Removal of Pre-Construction Primer - Task B	Type I or Type II	AP II or Type II	Type I or Type III	AP II
Refurbishment or Recoating of Anti-Fouling Coatings - Task C	Type II	Type IV	Type III or AP II	AP II
Total Removal of Anti-Fouling and Anti-Corrosive Hull Coatings - Task D	Type II	Type I	Type I, Type III, AP II, or AP VI	AP II
Removal or Refurbishment of Existing Deck Coatings - Task E	AP I (Type I Abrasives)	Type I	AP I	AP I
Removal or Refurbishment of Coatings from Interior Spaces - Task F	AP III	AP IV or AP V	AP IV, APV	AP III
Removal or Refurbishment of Coatings from Superstructure - Task G	Type II	Type I	Type I or Type III	AP VI
Removal or Refurbishment of Existing Bilge or Ballast Coatings - Task H	Type II	Type I	AP II, Type I	AP V
Cleaning of Machinery Housings - Task I	AP III	Type VI or VII	Type VI, AP IV or AP V	AP III
Cleaning of Non-ferrous Surfaces (Aluminum, Zinc) - Task J	Type II (Aluminum Oxide)	Type V	Type VII	AP II
Weld Seam Preparation - Task K	Type II	AP III or IV	AP V	AP V
Degreasing or Oil Removal - Task L	None - SSPC-SP 1 Cleaning Used	Type VI or Type VII	Type VI or Type VII	Type VII

6. Other Factors Affecting Abrasive Selection and Use

This section of the guide provides information about the influence of factors such as abrasive type, regulations and specifications on abrasive choice and procurement. Information is also given on how production and consumption rates are influenced by key variables in the database models. The variables covered include:

- Effect of changing the nozzle size and the pressure at the nozzle;
- Effect of changing the abrasive;
- Effect of changing the profile requirements, and
- Effect of changing the degree of cleaning.

The remainder of the guide consists of a series of appendixes described in brief below.

C.3 Appendices

Appendix 1. Major Factors Affecting Abrasive Selection and Costs

This appendix describes the major factors affecting abrasive selection.

Appendix 2. Relationships and Trade-offs in Abrasive Selections

This appendix provides information similar to that provided earlier in Section 2, but in greater detail.

Appendix 3. Factors Affecting Abrasive Blast Cleaning at Shipyards

Information is given on the role that abrasive type, size, or use can have on production and consumption rates. Also, guidance is given on the merits of alternatives to abrasive blast cleaning.

Appendix 4. Factors Limiting the Selection of Abrasives

These factors include the production rate of the coating process, health, safety and environmental issues, and the cost of the abrasive material itself.

Appendix 5. Equations for Use in Cost Modeling

This appendix presents a fully worked example of how to estimate surface preparation costs is also included.

Appendix 6. Regulatory Factors Affecting Abrasive Selection & Use

This appendix provides background information on regulatory factors affecting abrasive selection and use, such as environmental impact and health and safety considerations during abrasives use.

Tables of Abrasive Productivity & Consumption

The data tables are used in conjunction with the text guide are provided in a separate volume.

4. Economic Benefit to Shipyards

Significant savings can be realized through the efficient use of abrasive blasting. The User’s Guide along with the Performance and Cost Models assist a shipyard in performing abrasive blasting efficiently. Both of the SSPC and NSRP studies referenced in footnotes 1 and 2 on page 4 of this report describe how inefficient blast cleaning can increase surface preparation costs by up to 40%. The model described below will help shipyards determine how their operation compares to industry standards, and identify the means to improve their blast cleaning efficiency. It also provides a benchmark for evaluating process improvement efforts.

A comprehensive cost model has been developed which can be used as an adjunct to the guide. Through the use of this cost model one can estimate the impact of changing abrasive blasting operating conditions, such as pressure at the nozzle and nozzle size, on the cost of surface preparation. The cost model also allows the user to compare the use of different abrasives under related operating and process conditions.

A user of the guide can perform cost estimating for surface preparation tasks in one of two ways.

First, as an outline of all the cost components which the user should include in the cost estimate. Illustration of this step by step process is given in the rest of this section.

Second, as a cost modeling database that leads the user through the process of entering all the information needed to estimate the cost of the surface preparation task. All calculations are done by the cost modeling database application without additional user intervention.

Significant cost differences become apparent on changing assumptions which go into a model. Two examples showing significant cost differences are illustrated below in Section C. on page 25. The model depends on over twenty equations. The examples shown in Section C. illustrate typical inputs for cost modeling and the type of final result obtained. The equations for cost modeling are given in Appendix 5 to the Users Guide.

A. Information Needed for Cost Modeling

- Area to be blast cleaned in square feet, (A).
- Average number of hours per shift spent setting up equipment and staging for a work area (H1).
- Length of each shift (H2).
- Number of people per shift performing blast cleaning, (N1).
- Number of people per shift tending blast cleaning equipment, (N2).
- Number of shifts in each work-day (N3).
- Cost of the abrasive (typically in dollars per ton), (M1).
- Cost of labor (labor rates, including all taxes and overheads - $/hr,) (M2)[1]
- Cost of ($/hr) equipment operation, (M3)
- Cost of ($/hr) consumable equipment, (nozzles, hoses etc.), (M4)
- Waste disposal cost (S/Ton) (if a waste is hazardous also include the cost (S/Ton) of waste treatment prior to disposal), (M5)

1. Note that this assumes a constant labor rate for blasters and support personnel.

B. Quantities Computed By The Cost Model

The model computes the following quantities:

- (H3) -- Maximum hours available for surface preparation.
- (N4) -- Number of shifts used to complete a task.
- (N5) -- Total number of expended labor hours.
- (N6) --Total number of hours of equipment operation.
- (M6) -- Total labor cost for surface preparation.
- (M7) -- Total cost of equipment operation.
- (N8) -- Number of tons of abrasive used.
- (M8) -- Total cost of abrasive used.
- (M9) -- Total costs for consumable equipment.
- (M10) -- Total costs for waste disposal.

The details of the computations are given in Appendix 5 to the Users Guide.

C. Cost Model Use Examples

The following examples illustrate the cost estimating process for a job in which there is only one eight hour shift per day. Set-up and close-down takes 1.5 hours of the shift. Under C.1 the job is estimated based on a single use abrasive. Under C.2 the job is estimated based on the use of abrasive recycling.

C.1 Single Use Abrasive Costs

The values used for the various factors are:

- (A) -- Size of area to be blasted in square feet, 50,000 ft^2
- (H1) -- Average number of hours spent setting up equipment and staging for a work area per shift, 1.5 hours.
- (H2) -- Length of each shift, eight hours per shift.
- (N1) -- Number of people performing blasting in each shift, 2 blasters per shift.
- (N2) -- Number of people tending blasting equipment, one tender per shift.
- (N3) -- Number of shifts in each work-day, one shift per day.
- (M1) -- Abrasive cost (typically in dollars per ton), $100 per ton.
- (M2) -- Labor cost (fully burdened labor rates - $/hr), $40 per hour.
- (M3) -- Equipment operation cost ($/hr), $45 per hour.
- (M4) -- Consumable equipment cost, nozzles, hoses etc. - $/hr), $3.00 per hour.
- (M5) -- Waste disposal cost - $/ton), (M5), $30 per ton.
- In this example, the productivity estimate (P) is 250 ft^2 per hour and the estimated consumption rate (C) is 2,000 lbs/hr.

Using the equations shown in Appendix 5 of the Users Guide, the following costs are computed:

- M6 (Total labor cost of surface preparation) = $15,360;
- M7 (Total cost of equipment operation) = $5,760;
- M8 (Total cost of abrasive used) = $20,000;
- M9 (Total costs for consumable equipment) = $600, and
- M10 (Total costs for waste disposal) = $6,000.

Thus, using equation 12 from Appendix 5 of the Users Guide, our cost in dollars for this surface preparation task is:

$$M11(TotalCostofSurfacePreparation) = M6 + M7 + M8 + M9 + M10 = \$\ 47,720 \qquad \textbf{(1)}$$

Our cost per square foot for this task is obtained by dividing the total cost (M11) by the area cleaned (A).

$$CostperSquareFootofCleaning = \frac{M11}{A} = \frac{\$\ 47,720}{\$\ 50,000} = \$\ 0.951/(ft)^2 \qquad \textbf{(2)}$$

This gives a cost per square foot of $0.95.

C.2 Recycled Metallic Abrasive Cost

The values used for the various factors are:

- (A) -- Size of area to be blasted in square feet, 50,000 ft^2
- (H1) -- Average number of hours spent setting up equipment and staging for a work area per shift, 1.5 hours.
- (H2) -- Length of each shift, eight hours per shift.
- (N1) -- Number of people performing blasting in each shift, 2 blasters per shift.
- (N2) -- Number of people tending blasting equipment, one tender per shift.
- (N3) -- Number of shifts in each work-day, one shift per day.
- (M1) -- Abrasive cost (typically in dollars per ton), $500 per ton.
- (M2) -- Labor cost (fully burdened labor rates - $/hr), $40 per hour.
- (M3) -- Equipment operation cost ($/hr), $50 per hour.
- (M4) -- Consumable equipment cost, nozzles, hoses etc. - $/hr), $3.00 per hour.
- (M5) -- Waste disposal cost ($/ton), (M5), $30 per ton.
- The productivity estimate (P) is 190 ft^2 per hour and the estimated consumption rate (C) is 30 lbs/hr, (remember this is a recycled metallic abrasive, use rates are far lower when recycling is taken into consideration).

Using the equations shown in Appendix 5 of the User's Guide, the following costs are computed:

- M6 (Total labor cost of surface preparation) = $15,360;
- M7 (Total cost of equipment operation) = $6,400;
- M8 (Total cost of abrasive used) = $1,975;
- M9 (Total costs for consumable equipment) = $790, and
- M10 (Total costs for waste disposal) = $118.

Thus, using equation 12 from Appendix 5 of the users guide, our cost in dollars for this surface preparation task is:

$$M11(TotalCostofSurfacePreparation) = M6 + M7 + M8 + M9 + M10 = \$\ 24,643 \qquad \textbf{(3)}$$

As before the cost per square foot for this task is obtained by dividing the total cost (M11) by the area cleaned (A).

$$CostperSquareFootofCleaning = \frac{M11}{A} = \frac{\$\ 24,643}{\$\ 50,000} = \$\ 0.48/(ft)^2 \qquad \textbf{(4)}$$

This is roughly equal to a cost of $0.48 per square foot.

5. Conclusions & Recommendations

The user's guide to selection of abrasives provides significant benefits for shipyard painting departments. The document, along with the database application, delivers a coherent set of production and consumption rate information for a large number of abrasive materials.

The data found in the guide can serve three useful purposes:

1. Determining productivity and consumption rates for various abrasives and conditions;
2. Estimating the cost of a surface preparation task, and;
3. Process improvement exercises by shipyard paint departments.

Implementation of results from report

The following procedure is suggested for a shipyard seeking to benefit from the users guide.

The first application is to run the 11 step model to determine expected productivity and consumption rates based on the types of surface conditions, the specified end conditions, the types of abrasives used, the nozzle size and pressure, and the factors requiring adjustment. As part of this initial exercise the yard can determine if the operating parameters (nozzle size and pressure) are appropriate for the task being undertaken. The yard may also be able to determine if there is pra prospect for improving the operation by selecting an alternate abrasive for certain shipyard tasks.

A second use of the guide is to estimate the abrasive blast cleaning costs using the model's cost estimating features. These can be compared with the yards' own cost of surface preparation This exercise will require the yard to examine the blast cleaning process to determine factors such as the typical time for set up, and to consider the other advantages of altering the operating parameters.

In order for the yard to achieve significant improvement, it is important to determine the existing production and consumption rates, based on procedures outlined in the guide. These can be compared to industry norms and also can be used as benchmarks for improving the operations.

Suggested Follow-up Activities

The user's guide does not address the training of workers to use abrasives efficiently. This type of guidance goes beyond the scope of the user's guide. It is strongly suggested that either SNAME SP3, or the panel responsible for training programs within SNAME, address this issue in a follow-up to this project.

6. Supplementary Materials and Their Availability

This section identifies the project deliverables. Also, summaries are given of shipyard surveys and abrasive material specifications.

A. User’s Guide to Selection of Abrasives

The User’s Guide is the primary work product of the project. It is distributed by the NSRP.

B. Complete Listing of Project Deliverables

The seven deliverables are:

Deliverable 1: A report summarizing the different types of abrasives, industry specifications and consensus standards defining each abrasive type. A review of abrasive specifications is given in Section D, below.

Deliverable 2: A report describing the performance properties of different abrasive types. The report contains productivity and consumption data gathered from both a technical literature review, and surveys of abrasive manufacturers and shipyards. A summary of shipyard surveys is given in Section C, below.

Deliverable 3: A report describing the regulatory impact on abrasive selection and use from health, safety and environmental regulations. The report contains information about respiratory effects of different types of abrasive and also addresses waste disposal issues.

Deliverable 4: This report describes a process for modeling the abrasive productivity and consumption in typical shipyard applications. The data used to create the report is taken from the earlier industry surveys and technical literature sources identified in deliverable 2.

Deliverable 5: This report describes a second modeling exercise in which costs associated with abrasive use are assessed. This builds on the data contained in deliverable 4 and creates a cost model for surface preparation. Using the model, estimates of the costs for typical surface preparation tasks are made.

Deliverable 6: This guide to abrasive selection provides a user with a way to make abrasive selections based on their knowledge of the surface preparation task. The productivity and consumption information shown with the guide come from databases created for deliverables 4. Guidance on cost estimating is based on the model database created for deliverable 5

Deliverable 7: This report describes how the project was conducted and its key deliverables.

C. Data from Shipyard Surveys

Four shipyards responded to the survey of abrasive use. The survey asked for the abrasives used in surface preparation of various parts of the ship for both a total repaint and a partial repaint. Abrasive types were divided into metallic and non-metallic. Another question asked was whether the abrasive was recovered continuously or whether it was recovered after the blast. The results of this survey are tabulated for each shipyard, (Tables 4 - 7).

The responding shipyards are labelled as Shipyards A through D. The general location of these yards is as follows:

- Shipyard A is a gulf coast shipyard located in Louisiana;
- Shipyard B is located in the north-east United States;
- Shipyard C is located in Virginia;
- Shipyard D is located near the Great Lakes in Michigan.

To simplify shipyard responses and facilitate comparison of data the survey asked that answers conform to the following definitions:

Painting Task to be Performed

- Complete Repaint - Total removal of all coatings down to bare metal.
- Partial Repaint - Removal of loose paint and loose rust, (such as refurbishment of hull anti-foulant coatings).

Surface Preparation Process

- Non-metallic Continuous Recovery - Abrasive blast cleaning with mineral or organic abrasives. The process is accompanied by continuous recovery of abrasive grit for recycling and reuse.
- Non-metallic Post-blast Recovery - Abrasive blast cleaning with recovery of mineral or organic blast media at the end of a blast cleaning session for final disposal.
- Metallic Continuous Recycling - Abrasive blast cleaning with metallic abrasives with continuous recovery and reuse of material, (such as cleaning of plate steel or metal parts in a blast room).

Only shipyard A (Table 4) uses a different abrasive for a complete repaint than for a partial repaint. For complete repaint, steel shot with continuous recovery is the method of choice. However, for the partial repaint, the non-metallic abrasives, staurolite or coal slag, are used and are recovered after the blast for disposal. The same abrasive is used on all parts of the ship except for aluminum surfaces, which are chemically cleaned.

Shipyard B (Table 5) is the only one of the four shipyards that uses recyclable non-metallic abrasives. Garnet and/or aluminum oxide abrasives are used on underwater hull/ boottop, exterior topside, superstructures, and aluminum surfaces. Steel shot is used on decks and steel grit is used on tanks and interior surfaces.

Shipyard C (Table 6) uses garnet or coal slag with post-blast recovery on almost every part of the ship. Sometimes continuously recycled steel shot is used on the non-skid decks. Aluminum surfaces are cleaned with aluminum oxide or high pressure water jetting (HPWJ). Shipyard C also uses baking soda as the abrasive or HPWJ in specialized areas (such as steel motor housings).

Except for cleaning fuel tanks with HPWJ, Shipyard D (Table 7) cleans every part of the ship with coal slag. Whether the job is a full or partial repaint, the surface is blasted with coal slag, which is then recovered after the blast and discarded. There is no re-use of abrasive. Shipyard D did not indicate their preferred method for cleaning aluminum surfaces.

Note: Tables 1 through 3 are located in Section 3: Description of Project Tasks and Deliverables, beginning on page 6.

Table 4: Survey of Abrasive Practice at Shipyard A

	COMPLETE REPAINT[a]			PARTIAL REPAINT[b]		
	Non-Metallic Continuous Recovery[c]	Non-Metallic Post-blast Recovery[d]	Metallic Continuous Recycling[e]	Non-Metallic Continuous Recovery	Non-Metallic Post-blast Recovery	Metallic Continuous Recycling
Underwater Hull/Boottop (with organotin AF paint)			steel grit		staurolite coal slag	
Underwater Hull/Boottop (with organotin-free paint)			steel grit		staurolite coal slag	
Exterior Topside			steel grit		staurolite coal slag	
Decks Non-Skid			steel grit		staurolite coal slag	
Decks Other Coatings			steel grit		staurolite coal slag	
Superstructures			steel grit		staurolite coal slag	
Ballast or Bilge Tanks			steel grit		staurolite coal slag	
Fuel Tanks			steel grit		staurolite coal slag	
Interior Hulls			steel grit		staurolite coal slag	
Potable Water Tanks			steel grit		staurolite coal slag	
FRP Domes and Other Composite Surfaces			steel grit		staurolite coal slag	
Aluminum Entrances and Other Surfaces[f]						
Miscellaneous Surfaces and Substrates			steel grit		staurolite coal slag	

a. Complete Repaint - Total removal of all coatings down to bare metal.
b. Partial Repaint - Removal of loose paint and loose rust, (such as refurbishment of hull anti-foulant coatings).
c. Abrasive blast cleaning with mineral or organic abrasives. The process is accompanied by continuous recovery of abrasive grit for recycling and reuse.
d. Abrasive blast cleaning with recovery of mineral or organic blast media at the end of a blast cleaning session for final disposal.
e. Abrasive blast cleaning with metallic abrasives with continuous recovery and reuse of material, (such as cleaning of plate steel or metal parts in a blast room).
f. Chemical cleaning and paint removal are used on aluminum surfaces for both complete and partial repaint.

Table 5: Survey of Abrasive Practice at Shipyard B

	COMPLETE REPAINT			PARTIAL REPAINT		
	Non-Metallic Continuous Recovery	Non-Metallic Post-blast Recovery	Metallic Continuous Recycling	Non-Metallic Continuous Recovery	Non-Metallic Post-blast Recovery	Metallic Continuous Recycling
Underwater Hull/Boottop (with organotin AF paint)						
Underwater Hull/Boottop (with organotin-free paint)	garnet			garnet		
Exterior Topside	garnet Al oxide			garnet Al oxide		
Decks Non-Skid			steel shot			steel shot
Decks Other Coatings			steel shot			steel shot
Superstructures	garnet			garnet		
Ballast or Bilge Tanks			steel grit			steel grit
Fuel Tanks			steel grit			steel grit
Interior Hulls			steel grit			steel grit
Potable Water Tanks			steel grit			steel grit
FRP Domes and Other Composite Surfaces						
Aluminum Entrances and Other Surfaces	garnet Al oxide			garnet Al oxide		
Miscellaneous Surfaces and Substrates	garnet Al oxide			garnet Al oxide		

Table 6: Survey of Abrasive Practice at Shipyard C

	COMPLETE REPAINT			PARTIAL REPAINT		
	Non-Metallic Continuous Recovery	Non-Metallic Post-blast Recovery	Metallic Continuous Recycling	Non-Metallic Continuous Recovery	Non-Metallic Post-blast Recovery	Metallic Continuous Recycling
Underwater Hull/Boottop (with organotin AF paint)		garnet coal slag			garnet coal slag	
Underwater Hull/Boottop (with organotin-free paint)		garnet coal slag			garnet coal slag	
Exterior Topside		garnet coal slag			garnet coal slag	
Decks Non-Skid		garnet	steel shot		garnet coal slag	steel shot
Decks Other Coatings		garnet coal slag			garnet coal slag	
Superstructures		garnet coal slag			garnet coal slag	
Ballast or Bilge Tanks		garnet coal slag			garnet coal slag	
Fuel Tanks		garnet coal slag			garnet coal slag	
Interior Hulls		garnet coal slag			garnet coal slag	
Potable Water Tanks		garnet coal slag			garnet coal slag	
FRP Domes and Other Composite Surfaces		garnet coal slag			garnet coal slag	
Aluminum Entrances and Other Surfaces[a]		Al oxide			Al oxide	
Miscellaneous Surfaces and Substrates[a]		garnet baking soda coal slag			garnet coal slag	

a. High pressure water jetting (HPWJ) is used on miscellaneous surfaces and substrates for complete repainting and on aluminum surfaces for partial repaint.

Table 7: Survey of Abrasive Practice at Shipyard D

	COMPLETE REPAINT			PARTIAL REPAINT		
	Non-Metallic Continuous Recovery	**Non-Metallic Post-blast Recovery**	**Metallic Continuous Recycling**	**Non-Metallic Continuous Recovery**	**Non-Metallic Post-blast Recovery**	**Metallic Continuous Recycling**
Underwater Hull/Boottop (with organotin AF paint)		coal slag			coal slag	
Underwater Hull/Boottop (with organotin-free paint)		coal slag			coal slag	
Exterior Topside		coal slag			coal slag	
Decks Non-Skid		coal slag	steel shot		coal slag	steel shot
Decks Other Coatings		coal slag			coal slag	
Superstructures		coal slag			coal slag	
Ballast or Bilge Tanks		coal slag			coal slag	
Fuel Tanks[a]						
Interior Hulls		coal slag			coal slag	
Potable Water Tanks		coal slag			coal slag	
FRP Domes and Other Composite Surfaces		coal slag			coal slag	
Aluminum Entrances and Other Surfaces						
Miscellaneous Surfaces and Substrates		coal slag			coal slag	

a. High pressure water jetting (HPWJ) is used on fuel tanks for both complete repainting for partial repaint.

D. Specifications and Standards for Blast Cleaning Abrasives

A comparison of all abrasive specifications reviewed during the production of deliverable item 1 is given in this section. The comparison begins with a listing of relevant specifications for mineral and metallic abrasives. Table 8 shows the listing of International Organization for Standardization (ISO) abrasive specifications for metallic abrasives, following which in Table 9 are the ISO specifications for mineral abrasives.

Table 8: ISO Metallic Abrasive Specifications

Designation	Title	Availability
ISO 11124	**Specification for metallic blast-cleaning abrasives**	
Part 1	General introduction and classification	yes
Part 2	Chilled-iron grit	yes
Part 3	High-carbon cast-steel shot and grit	yes
Part 4	Low-carbon cast-steel shot	yes
Part 5	Cut steel wire	no[a]
ISO 11125	**Test methods for metallic blast-cleaning abrasives**	
Part 1	Sampling	yes
Part 2	Determination of particle size distribution	yes
Part 3	Determination of hardness	yes
Part 4	Determination of apparent density	yes
Part 5	Determination of percentage defective particles and of microstructure	yes
Part 6	Determination of foreign matter	yes
Part 7	Determination of moisture	yes
Part 8	Determination of abrasive mechanical properties	no

a. The denotation of "no" for standard availability indicates that a draft standard is under review by the responsible ISO Technical Committee.

Table 9: ISO Specifications for Mineral Abrasives

ISO 11126	**Specifications for non-metallic blast-cleaning abrasives**	
Part 1	General introduction and classification	yes
Part 2	Silica sand	no
Part 3	Copper refinery slag	yes
Part 4	Coal furnace slag	yes
Part 5	Nickel refinery slag	yes
Part 6	Iron furnace slag	yes
Part 7	Fused aluminum oxide	yes
Part 8	Olivine sand	yes
Part 9	Staurolite	no
Part 10	Garnet	no
ISO 11127	**Test methods for non-metallic blast-cleaning abrasives**	
Part 1	Sampling	yes
Part 2	Determination of particle size distribution	yes
Part 3	Determination of apparent density	yes
Part 4	Assessment of hardness by a glass slide test	yes
Part 5	Determination of moisture	yes
Part 6	Determination of water-soluble contaminants by conductivity measurement	yes
Part 7	Determination of water-soluble chlorides	yes
Part 8	Determination of abrasive mechanical properties	no

Table 10 presents selected definitions common to all abrasive materials used. Table 11 includes definitions unique to metallic abrasives, while Table 12 contains unique definitions for mineral abrasives as used in ISO specifications. Common abbreviations for abrasive material types, along with the profile expectations, taken from ISO specifications are shown in Table 13.

Table 10: Selected ISO Definitions for Any Abrasive Materials

Term	Definition
blast-cleaning abrasive:	Solid material intended to be used for abrasive blast-cleaning.
abrasive blast-cleaning:	Impingement of a high-kinetic-energy stream of blast-cleaning abrasive on to the surface to be prepared.
shot:	Particles that are predominantly round, that have a length of less than twice the maximum particle width and that do not have edges, broken faces or other sharp surface defects.
grit:	Particles that are predominantly angular, that have fractured faces and sharp edges and that are less than half-round in shape.
cylindrical:	Sharp-edged particles, having a diameter to length ratio of 1:1, cut so that their faces are approximately at right angles to their centerline.
defect:	A fault or weakness in an abrasive which, if present at or above a given level, may be detrimental to the performance of the abrasive.
void:	A smooth-surfaced internal cavity considered undesirable when greater than 10% of the cross-sectional area of a particle.
shrinkage defect:	An internal cavity with a rough dendritic surface or zone of microporosity, considered undesirable when greater than 40% of the cross-sectional area of a particle.
crack:	A linear discontinuity that has a length-to-width ratio of 3:1 or greater, that extends over more than 20% of the diameter or shortest dimension of a particle and that is radial in direction.
foreign matter:	Any material or particles mixed with the abrasive which are not attached to the abrasive particles and which are nonmagnetic.

Table 11: Selected ISO Definitions for Metallic Abrasive Materials

Term	Definition
chilled-iron grit:	A metallic blast-cleaning abrasive produced by crushing various chilled-iron shot sizes into sharp-edged angular particles.
chilled iron shot:	A metallic blast-cleaning abrasive produced by a casting process in which molten iron is formed into shot by means of an atomization process.
high-carbon cast-steel shot:	A metallic blast-cleaning abrasive produced by a casting process in which molten high-carbon steel is formed into shot by means of an atomization process.
high-carbon cast-steel grit:	A metallic blast-cleaning abrasive produced by crushing various high-carbon cast-steel shot sizes into sharp-edged angular particles.
low-carbon cast-steel shot:	A metallic blast-cleaning abrasive produced by a casting process in which molten low-carbon steel is formed into shot by means of an atomization process.

Table 12: Selected ISO Definitions for Mineral Abrasives

Term	Definition
copper refinery slag:	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from copper smelting. It is basically iron silicate slag.
coal furnace slag:	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing, from slag originating when coal is burned in coal-fired power stations. It is basically aluminum silicate slag.
nickel refinery slag:	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from nickel smelting. It is basically iron silicate slag.
iron furnace slag:	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from iron smelting. It is basically calcium silicate slag.
fused aluminum oxide:	A synthetic mineral blast-cleaning abrasive, which is classified as two types, A and WA.
Type A is mainly composed of crystalline corundum which is brown in color and consists of a solid solution containing a minimum of 94% aluminum oxide and a maximum of 4% titanium dioxide. Type A is produced by fusing bauxite with the appropriate quantity of titanium dioxide and reducing agent in an electric furnace, cooling to form lumps and then crushing and sieving to size.	
Type WA consists of crystalline corundum which is whitish in color and contains at least 99% aluminum oxide. It is produced by fusing, in an electric furnace, pure aluminum oxide and is refined.	
olivine sand:	A mineral manufactured from the naturally occurring mineral olivine which is crushed by a mechanical process, dried and sieved and prepared for use as a blast-cleaning abrasive. Olivine is a magnesium/iron silicate with the chemical formula $MgO \cdot SiO_2 \cdot Fe_2O_3$ (Mg, Fe)Si2O4.
staurolite mineral:	A naturally occurring mineral sand, staurolite, which is mined, concentrated, scrubbed, dried, and further purified using high-intensity electrostatic and magnetic processes, and prepared for use as a blast cleaning abrasive. Staurolite is an iron/aluminum silicate with the chemical formula $FeAl_5SiO_{12}OH$.
garnet:	A material manufactured from the naturally occurring mineral, garnet, which is dried and sieved, with or without mechanical crushing, and prepared for use as a blast cleaning abrasive. There are two significantly different garnet minerals used for blast cleaning. Almandite garnet is an iron aluminum silicate with the chemical formula $Fe_3Al_2(SiO_4)_3$. Andradite garnet is a calcium iron silicate with the chemical formula $Ca_3Fe_2(SiO_4)_3$. These garnet abrasives differ in appearance, hardness, specific gravity, and other properties.

Table 13: Commonly Used Blast Cleaning Abrasives for Steel Substrate Preparation

Type			Abbreviation	Initial Particle Shape	Particle Shape Comparator[a]	Specification
Metallic (ISO 11124)	Cast Iron	Chilled	M/CI	G	G	ISO 11124-2
	Cast Steel	High-carbon	M/HCS	S or G	S[b]	ISO 11124-3
		Low-carbon	M/LCS	S	S	ISO 11124-4
	Cut Steel Wire	-	M/CW	C	S[b]	ISO 11124-5[c]
Natural (non-metallic) (ISO 11126)	Silica Sand		N/SI	G	G	ISO 11126-2[c]
	Olivine Sand		N/OL	G	G	ISO 11126-8
	Staurolite		N/ST	S/G	S	ISO 11126-9[c]
	Garnet		N/GA	G	G	ISO 11126-10[c]
Synthetic (non-metallic) (ISO 11126)	Iron Furnace Slag	(Calcium silicate slags)	N/FE	G	G	ISO 11126-6
	Copper Refinery Slag	(Ferrous silicate slags)	N/CU	G	G	ISO 11126-3
	Nickel Refinery Slag	(Ferrous silicate slags)	N/NI	G	G	ISO 11126-5
	Coal Furnace Slag	(Aluminum silicate slags)	N/CS	G	G	ISO 11126-4
	Fused Aluminum Oxide		N/FA	G	G	ISO 11126-7

Particle shape designation	ISO 8503-2
Shot - round	(S)
Grit - angular, irregular	(G)
Cylindrical - sharp-edged	(C)

a. A comparator is to be used when assessing the resultant surface profile. The method is described in the ISO 8503-2 specification. The classes of abrasive shape from ISO 8503-2 are given in the lower section of this table. These classes of abrasive shape are used to label the corresponding surface profile comparator suggested in ISO 8503-2.

b. Certain abrasives change shape rapidly when used. The appearance of the profile approaches that of the "shot" comparator.

c. As of November 1997, ISO abrasive specifications had not been issued for Cut Steel Wire, Staurolite, Garnet or Silica Sand.

Table 14: ISO Metallic Blast Cleaning Abrasives Hardness Requirements

Abrasive	Hardness[a] (Vickers) HV
Chilled-iron grit	650 minimum
High-carbon cast-steel shot	390 to 530
High-carbon cast-steel grit Five discrete ranges of hardness defined.	390 to 530 470 to 610 570 to 710 700 minimum
Low-carbon cast-steel shot	390 to 520

a. Hardness is measured with ISO Standard 11125-3

Hardness requirements for metallic abrasives, taken from ISO specifications are shown above in Table 14, and particle size shape requirements are shown below in Table 15. High carbon steel grit has five ranges of hardness. These ranges have their origins in the abrasive hardness ranges for high-carbon steel grit in the Society of Automotive Engineers (SAE) J1993 recommended practice for cast steel grit. SAE J1993 contains three hardness ranges, roughly corresponding to HV ranges 390 to 530, 530 to 700 and 700 minimum values. European practice is to span hardness ranges as shown in first three hardnesses for high-carbon cast steel grit. The four ranges defined in the resulting ISO 11124-3 standard are a compromise to minimize commercial disruption to the European and U.S. metallic abrasive industries. The fourth range of HV 700 minimum was retained to maintain U.S. specification compliance following issuance of the ISO 11124-3 standard. Composition requirements for ISO metallic abrasives are shown in Table 16 on page 41. The ISO specifications for metallic abrasives are directly modeled on the respective SAE specifications in all regards except sizing. A comparison of sizing information is given later in Table 23 on page 46 for SAE, ISO, Steel Founder's Society of America, (SFSA) and Deutsche Indutsrie Norm, (DIN) specifications.

Table 15: ISO Particle Requirements for Metallic Blast-Cleaning Abrasives

	Type of metallic abrasive (ISO 11124)				
Property	**Chilled-iron Grit (11124-2)**	**High-carbon cast-steel Shot (11124-3)**	**High-carbon cast-steel Grit (11124-3)**	**Low-carbon cast-steel Shot (11124-4)**	**Test method**
Defects					ISO 11125-5
Particle shape	max. 10% shot or more than half-round	max. 5% non-round	max. 10% shot or more than half-round for grit up to 700 HV; max. 5% for grit above 700 HV	max. 15% non-round	
Voids	max. 10%	max. 10%	max. 10%	max. 15%	
Shrinkage defect	max. 10%	max. 10%	max. 10%	max. 5%	
Cracks	max. 40%	max. 15%	max. 40%	none	
Total defects	max. 40%	max. 20%	max. 40%	max. 20%	
Particles with more than one of the above defects shall be counted only once in this total.					

Table 16: ISO Composition Requirements for Metallic Blast-Cleaning Abrasives

	Type of metallic abrasive (ISO 11124)				
Property	**Chilled-iron Grit (11124-2)**	**High-carbon cast-steel Shot (11124-3)**	**High-carbon cast-steel Grit (11124-3)**	**Low-carbon cast-steel Shot (11124-4)**	**Test method**
Structure	Chilled-iron grit abrasives shall have a white iron type microstructure of iron carbide in martensite. Partial decarburization, free graphite or ferrite shall be less than 5% in any single particle. (Note 1) No more than 15% of the particles tested shall have undesirable microstructure.	Cast-steel shot and grit abrasives shall have a uniform martensite and/or bainite microstructure, tempered to a degree consistent with the hardness range, with fine, well-distributed carbides, if any. Partial decarburization, carbide networks and interdendritic grain boundary segregation with high-temperature transformation products such as pearlite are undesirable. No more than 15% of the particles tested shall have undesirable microstructure.		Low-carbon cast-steel shot abrasives shall have a bainitic or martensitic structure. (Note 1) No more than 15% of the particles tested shall have undesirable microstructure.	ISO 11125-5
Chemical Composition	min. 1.7% (m/m) carbon content in the finished product	Carbon 0.80% to 1.2% (m/m) Manganese 0.35% to 1.2% (m/m) Silicon min. 0.4% (m/m) Sulfur max. 0.05% (m/m) Phosphorus max. 0.05% (m/m) The manganese content shall be sufficiently high to achieve the required hardness throughout the section of all particles.		Carbon 0.08 to 0.20% Manganese 0.35 to 1.50% Silicon 0.10 to 2.00% Sulfur max. 0.05% Phosphorus max. 0.05%	ISO 9556 ISO 629 ISO 439 ISO 4935 ISO 10714
Hardness	90% of the particles tested shall have a hardness above 650 HV. (Note 2)	90% of the particles tested shall have a hardness within one of the ranges specified below: (Note 3) 390 to 530 HV	390 to 530 HV 470 to 610 HV 570 to 710 HV 700 HV minimum	90% of the particles tested shall have a hardness range of 390 to 520 HV. (Note 2)	ISO 11125-3
Apparent density	min. 7000 kg/m^3 (7.0 kg/dm^3)				ISO 11125-4
Foreign matter (including slag)	Max. 1% (m/m)				ISO 11125-6
Moisture	max. 0.2% (m/m)				ISO 11125-7

Below begins a series of tables describing properties of mineral abrasives. Unlike the ISO specifications for metallic abrasives the corresponding U.S. military or industry specifications are not directly equal to the ISO specifications. Table 17 on page 42 summarizes composition and fundamental characteristic requirements for the mineral abrasives described in specifications under ISO designation 11126. Table 18 on page 42 provides a point of comparison with the requirements for mineral abrasives in SSPC-AB 1, “Specification for Mineral and Slag Abrasives.” Table 19 on page 43 compares the common property requirements of SSPC-AB 1 with the various parts of ISO 11126. These property requirements are then compared with those found in MIL-22262B(SH), “Abrasive Blasting Media, Ship Hull Blast Cleaning.” Another military specification of importance to the shipbuilding industry is MIL-G5634-C, (superseded by A-A-1722 - GRAIN, ABRASIVE (SOFT BLASTING),) this covers requirements for agricultural by-product abrasives.

Table 17: ISO Requirements for Non-Metallic Blast Cleaning Abrasives

Property		Copper Refinery Slag (11126-3)	Coal Furnace Slag (11126-4)	Nickel Refinery Slag (11126-5)	Iron Furnace Slag (11126-6)	Fused Aluminum Oxide (11126-7)	Olivine Sand (11126-8)	Test Method	Staurolite[a]	Garnet[a]
Particle size range and distribution		See Table 20						ISO 11127-2	See Table 20	
Apparent density	kg/m^3	3300 to 3900	2400 to 2600	3300 to 3900	3000 to 3300	3900 to 4000	3000 to 3300	ISO 11127-3	2100 to 2300	3100 to 4100
	$[kg/dm^3]$	[3.3 to 3.9]	[2.4 to 2.6]	[3.3 to 3.9]	[3.0 to 3.3]	[3.9 to 4.0]	[3.0 to 3.3]		[2.1 to 2.3]	[3.1 to 4.1]
Mohs hardness		min. 6	min. 6	min. 6	min. 6	min. 6	min. 6	ISO 11127-4	min. 5.5	min. 6
Moisture	% (m/m)	max 0.2	max 0.2	max 0.2	max 0.2	max 0.2	max 0.2	ISO 11127-5	max 0.1	max 0.2
Conductivity of aqueous extract (mS/m)		max. 25	max. 25	max. 25	max. 25	max. 25	max. 25	ISO 11127-6	max. 25	max. 25
Water-soluble chlorides% (m/m)		max. 0.0025	max. 0.0025	max. 0.0025	max. 0.0025	max. 0.0025	max. 0.0025	ISO 11127-7	max. 0.0025	max. 0.0025

a. As of December, 1997, ISO 11126, Part 2: Silica sand, Part 9: Staurolite and Part 10: Garnet have not been issued.

Table 18: SSPC-AB 1[1] Requirements for Non-Metallic Blast Cleaning Abrasives

Properties	Requirement		Test Procedure
	min.	max.	
Specific gravity	2.5		ASTM C 128
Hardness	6		Mohs scale
Weight change on ignition	-1.0%	+0.05%	Heat to 750° C (1382° F)
Water soluble contaminant		1000 µS/cm	ASTM D 4940
Moisture content		0.5%	ASTM C 566
Oil content		none	Observe surface of water extract.

1. Steel Structures Painting Council specification SSPC-AB 1, Mineral and Slag Abrasives.

Table 19: ISO, SSPC and Military Specifications Compared - Mineral Abrasives

Requirement	ISO	SSPC	Military[c]	Method
Crystalline Silica	Varies	3 Classes Allowed: A - <1.0%; B - <5.0%; C - no limit	<1.0%	Military - IR Spectra SSPC - IR Spectra or X-Ray Diffraction
Apparent Density	Varies see Table 17	2.5 minimum	2.5 minimum	ISO 11127-3 Others - ASTM C188
Hardness	Varies see Table 17	6	6	ISO 11127-4 Others - Moh's Scale
Moisture Content	<0.2%	<0.5%	<0.5%	ISO 11127-5 Others - ASTM C 566
Conductivity of aqueous extract mS/m	<25	<1000	<290	ISO 11127-6 Others ASTM D 4940
Water-soluble chlorides% (m/m)	<0.0025	Not Set	<0.03%	ISO 11127-7 Military - ASTM D 1411
Weight Change on Ignition	Not Set	> -1.0% - <5.0%	> -1.0% - <5.0%	Military - Heat to 1000°C SSPC - Heat to 750°C
Oil Content	Not Set	Visibly free	<0.03%	SSPC - Visual Military - Freon Extraction
Size Gradation	Varies - see Table 20	Classed According to Profile Achieved[a]	Graded by Batch	ISO 11127-2 Others - ASTM C 117
Friability	Not Set	Not Set	California Limits[b]	California Test Method 371-A
General Composition	Varies - see Table 12	Not Set	Not Set	
Soluble Metals	Not Set	Not Set	Table I[c]	Military - California Administrative Code Title 22
Trace Metals	Not Set	Not Set	Table II[c]	Military - as above
Toxic Materials	Not Set	Not Set	Table III[c]	EPA TCLP Method[d]
Radioactivity	Not Set	Not Set	<20 picoCuries/g	In MIL-A-22262B(SH)

a. Grade 1, 13 to 38 µm (0.5 to 1.5 mils), Grade 2, 25 to 64 µm (1.0 to 2.5 mils), Grade 3, 51 to 89 µm (2.0 to 3.5 mils),Grade 4, 75 to 127 µm (3.0 to 5.0 mils), Grade 5, 102 to 152 µm (4.0 to 6.0 mils)

b. Meet California Administrative Code, title 17, subchapter 6, section 92530 and be present on list of California Air Resources Board (CARB) accepted abrasives

c. From MIL-A-22262B(SH)

d. Federal Register (FR), Volume 55, paragraph 11798, March 19, 1990 (55 FR 11798), Toxicity Characteristic Leaching Procedure (TCLP).

Table 20: ISO Size Designations for Mineral Abrasive

Particle size range[a] (mm)		0.2 to 0.5	0.2 to 1	0.2 to 1.4	0.2 to 2	0.2 to 2.8	0.5 to 1	0.5 to 1.4	1 to 2	1.4 to 2.8
Oversize										
Sieve size	mm	0.5	1	1.4	2	2.8	1	1.4	2	2.8
Residue% (m/m)	max	10	10	10	10	10	10	10	10	10
Nominal size										
Sieve size	mm	0.2	0.2	0.2	0.2	0.2	0.5	0.5	1	1.4
Residue% (m/m)	max	85	85	85	85	85	80	80	80	80
Undersize										
Sieve size	mm	0.2	0.2	0.2	0.2	0.2	0.5	0.5	1	1.4
Through-flow% (m/m)	max	5	5	5	5	5	10	10	10	10

a. Taken from the ISO 11127-2 standard.

Table 21: Typical Data from SSPC and Other Laboratory Studies

Property[a]	Copper Refinery Slag	Coal Furnace Slag	Nickel Refinery Slag	Iron Furnace Slag	Fused Aluminum Oxide	Olivine Sand	Test Method	Staurolite	Garnet	Silica Sand
Specific gravity	3.3	2.8	3.2		3.8			4.5	4.0	2.7
Mohs hardness[b]	>6	≥6	≥6		≥6			≥6	≥6	4 to 6
Conductivity of aqueous extract mS/m	5.6 to 130	2.4 to 16	26				(Note1)	38 to 46	9 to 50	4 to 34
pH	8.2 to 10.3	4.8 to 7.7	7				(Note1)	7.6 to 8	7 to 9.8	5.3 to 9.3
Water-soluble chlorides% (m/m)							(Note1)			

a. Results from a round-robin study of abrasive material conformance with ASTM D 4940 on behalf of ASTM D01 with participation by SSPC and other laboratories.
b. Data supplied by abrasive manufacturers submitting samples to round robin.

Table 22: Non-Metallic Blast Cleaning Abrasives

Abrasive	ISO Definition	Apparent density	
		kg/m^3	kg/dm^3
Copper Refinery Slag	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from copper smelting. It is basically iron silicate slag.	3300 to 3900	3.3 to 3.9
Coal Furnace Slag	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing, from slag originating when coal is burned in coal-fired power stations. It is basically aluminum silicate slag.	2400 to 2600	2.4 to 2.6
Nickel Refinery Slag	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from nickel smelting. It is basically iron silicate slag.	3300 to 3900	3.3 to 3.9
Iron Furnace Slag	A synthetic mineral blast-cleaning abrasive manufactured, by granulation in water, drying and sieving, with or without mechanical crushing processes, from slag originating from iron smelting. It is basically calcium silicate slag.	3000 to 3300	3.0 to 3.3
Fused Aluminum Oxide	A synthetic mineral blast-cleaning abrasive, which is classified as two types, A and WA. Type A is minimum 94% aluminum oxide and maximum 4% titanium dioxide and is brown in color. Type WA contains at least 99% aluminum oxide and is whitish in color.	3900 to 4000	3.9 to 4.0
Olivine Sand	A mineral manufactured from the naturally occurring mineral olivine which is crushed by a mechanical process, dried and sieved and prepared for use as a blast-cleaning abrasive. Olivine is a magnesium silicate.	3000 to 3300	3.0 to 3.3
Staurolite	A naturally occurring mineral sand which is mined, concentrated, scrubbed, dried, and further purified using high-intensity electrostatic and magnetic processes, and prepared for use as a blast cleaning abrasive. Staurolite is an iron/aluminum silicate.	2100 to 2300	2.1 to 2.3
Garnet	A material manufactured from the naturally occurring mineral, garnet, which is dried and sieved, with or without mechanical crushing, and prepared for use as a blast cleaning abrasive. There are two different garnet minerals used for blast cleaning.	3100 to 4100	3.1 to 4.1

Table 23: Metallic Shot and Grit Size Designations Compared

	ISO	SAE J444[a,b]	SFSA 20-66[c] and 21-68[d]	BS 2451[e]	DIN 8201 Teil 2
Shot[f]	S400	S1320		S1320	--
	S300	S1110		S1110	--
	S280	S930		S950	--
	S240	S780	780	S800	2,0 to 2,8
	S200	S660	660	S660	1,6 to 2,24
	S170	S550	550	S550	1,25 to 2,0
	S140	S460	460	S470	--
	S120	S390	390	S390	1,0 to 1,6
	S100	S330	330	S340	0,8 to 1,25
	S080	S280	280	--	0,8 to 1,25
	S070	S230	230	S240	0,6 to 1,0
	S060	S170	170	S170	0,4 to 0,8
	S040	S110		S120	0,3 to 0,6
	S030	S70		S070	0,2 to 0,4
					DIN 8201 Teil 3
Grit[g]	--	--		G95	--
	G240	G10	G10	G80	2,0 to 2,8
	G200	G12	G12	G66	1,6 to 2,24
	G170	G14	G14	G55	1,25 to 2,0
	G140	G16	G16	G47	1,0 to 1,6
	G120	G18	G18	G39	1,0 to 1,6
	G100	G25	G25	G34	0,8 to 1,25
	G070	G40	G40	G24/G17	0,6 to 1,0/0,4 to 0,8
	G050	G50	G50	G12	"0,3 to 0,6"
	G030	G80		G07	"0,2 to 0,4"
	G020	G120		G05	"0,16 to 0,3"
	G010	G200		G02	"0,1 to 0,2"
	G005	G325		G02	--

a. Military requirements for steel shot and steel grit, contained in MIL-S-851D, follow these levels
b. Size requirements for newly manufactured or re-manufactured abrasive in SSPC-AB 3 follow SAE J444.
c. SFSA 20-66 Standard Specification for Cast Steel Abrasives.
d. SFSA 21-68 Standard Specification for Malleable Steel Abrasives.
e. British Standard 2451 for Steel Abrasives.
f. Most steel shot specifications use the prefix letter "S" with a grade of steel shot.
g. Most steel grit specifications use the prefix letter "G" with a grade of steel grit.

D.1 Recent SSPC Specifications for Metallic Abrasives

SSPC-AB 2

The SSPC-AB 2 "Specification for Cleanliness of Recycled Ferrous Metallic Abrasives," was issued in May, 1996. The specification defines cleanliness requirements for recycling metallic abrasive material. Specific allowances of interest in recycled metallic abrasives include:

- Less than 1% by weight of non-magnetic material in the recycled metallic abrasive;
- Less than 0.1% by weight of lead (when tested in accordance with ASTM D 3335, digestion and atomic absorption).
- Water soluble contaminants are limited to less than 1,000 micromhos/cm.

It should be noted that metallic abrasives procured for use in naval shipbuilding are expected to meet the requirements of the governing military specification (MIL-S-851D), both before and after recycling. An abrasive with contaminant levels permitted at the levels allowed in SSPC-AB 2 will not meet these requirements.

SSPC-AB 3

The SSPC-AB 3 "Specification for Newly Manufactured or Re-Manufactured Abrasives," was issued in May, 1997. This specification corresponds with the SAE requirements from SAE J444 for sizing of metallic abrasive grit. The requirements for carbon content of the steel grit in SSPC-AB 3 differ from those shown in ISO 11124-3 (for high-carbon steel grit and shot). The specified level of allowed carbon in SSPC-AB 3 is up to 1.5%. The specified range of carbon in ISO 11124-3 is between 0.8% to 1.2%. The higher range of allowed carbon in the SSPC specification permits re-manufactured steel grits that do not meet the requirements of the ISO standard. The expectation of the SSPC-AB 3 standard is that the primary control on exact composition will be the hardness defined by the buyer.

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